TESTING AND MONITORING: VALIDATING PERFORMANCE OF ACCELERATED CONSTRUCTION, NEW BRIDGE MATERIALS AND DESIGN/EVALUATION METHODS

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ABSTRACT

In recent years, the Iowa Department of Transportation (Iowa DOT) has focused efforts on investigating the use of new high performance materials, design and construction methods, and supplemental maintenance methods. These efforts are intended to increase the life span of bridges and meet the Iowa DOT's objectives for building and maintaining cost-effective, safe bridges. Bridge testing and monitoring has proven beneficial in helping evaluate the performance of implemented innovations, and the Iowa DOT has enlisted the help of the Bridge Engineering Center at Iowa State University (ISU) with these testing and monitoring efforts.

This paper will provide case studies related to field testing and monitoring of accelerated construction projects, other innovative construction projects, and ultra high performance materials associated with precast concrete components. The case studies presented will describe the objective of the testing and monitoring, briefly describe the bridges and the instrumentation and monitoring, as well as comment on the value of the testing and monitoring to the Iowa DOT. The case studies will focus on the following topics: 1) evaluation and testing of Ultra High Performance Concrete girders; and 2) construction monitoring and long-term monitoring of design details for various precast components.

Keywords: Ultra High Performance Concrete, Steel Fibers, Ductal® Concrete, LaFarge North America, Bulb-Tee, Reactive Powder Concrete, High Strength Materials, Accelerated Construction, Rapid Bridge Replacement, Rapid Construction, Post-Tensioned, Precast Concrete, Precast Bridge Elements, Precast Pier, Abutment Caps, Bridge Field Testing, Diagnostic Testing, Laboratory Testing, Bridge Monitoring, Sensors

BACKGROUND

The Iowa Department of Transportation (Iowa DOT) Office of Bridges and Structures (Bridge Office) is responsible for the design and construction of highway structures in Iowa and maintains about 4,000 bridges. In recent years, the Bridge Office has focused efforts on investigating the use of new high performance materials, design and construction methods and supplemental maintenance methods. These efforts are intended to increase the life span of bridges in meeting the objectives for building and maintaining cost-effective, durable and safe bridges. The condition of the nation's infrastructure has received a significant amount of attention in recent months generating serious debate about the safety of bridges thus making this endeavor a priority. Taking advantage of a strong relationship between the Iowa DOT and Iowa State University (ISU), the Bridge Office enlisted the help of the Bridge Engineering Center at ISU with these testing and monitoring efforts.

Bridge testing can be used in numerous situations, supplementing typical evaluation methods used by the Iowa DOT and is composed of both laboratory and field components. Typically, the laboratory component takes place early on in an effort to validate design assumptions prior to construction but it may also continue during the remaining phases of the project. As for field testing, the concept involves taking field measurements (using various sensors and monitoring systems) on a bridge to identify the actual structural response (movement, forces, etc.), typically under vehicle loading conditions. The field data are usually compared with some design-based structural parameter to determine if the response is appropriate. The data may also be used to calibrate an analytical model to provide a more detailed structural assessment (e.g., a load rating to determine safe bridge capacity). Diagnostic testing can also be used to help identify deterioration, damage, or to assess the integrity of an implemented repair or strengthening method. In cases where Iowa DOT engineers have investigated the use of innovative materials [e.g., high performance steel, Ultra-High Performance Concrete (UHPC) or fiber reinforced polymers] and design/construction methods, they have used testing as part of the program for evaluating bridge performance.

SENSORS AND MONITORING SYSTEMS

One key component associated with the testing is the use of sensors and monitoring or data collection systems. Each project has unique objectives, so the sensor components and monitoring systems used differ depending on needed results. Most testing sensors are conventional electronic-based devices (Fig. 1) such as displacement transducers, foil or vibrating wire strain gages, and accelerometers for monitoring vibration characteristics.

For typical one day tests, the Iowa DOT has invested in a testing system that includes sensors and a monitoring and evaluation system (composed of hardware and software) from Bridge Diagnostics Incorporated (BDI). This BDI system uses electronic-based strain gages that are reusable (Fig. 2). Innovative sensors and data collection systems (e.g., fiber optics-based sensors that use light wave mechanics, unlike more typical electronic-based sensors) have also been used for monitoring several Iowa bridge projects. Fiber optic sensors have been used for longer term, continuous monitoring (Fig. 3 and 4).

Figure 1. Displacement and foil strain sensors used to evaluate connection structural response

Figure 2. Multiple BDI strain sensors on bridge girders for load rating test

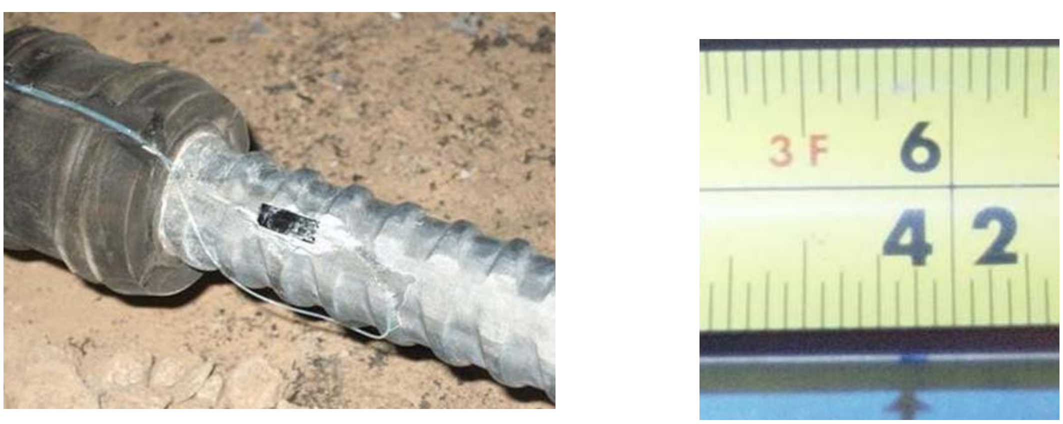


Figure 3. Uncoated fiber on hanger rod with sensor (in black package) bonded to the specimen. The actual fiber optic sensor within the fiber is extremely small (designated by arrow pointing to blue region)

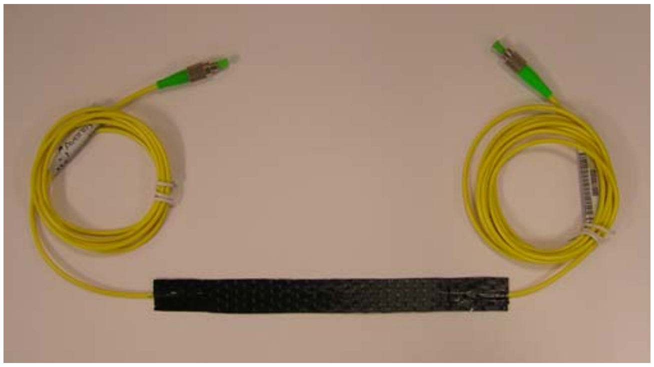


Figure. 4 Coated fiber leads on either end of fiber optic sensor which is contained within a larger (210 mm x 20 mm) carbon fiber package bonded directly to a bridge member

CASE STUDIES

In this paper the authors will illustrate the value of the testing and monitoring program that was used on several Iowa projects. Given the scope of the paper and the number of projects presented, only brief details of the testing and evaluation results are presented. Additional details may be found in the listed references for case study. These projects involved the use of innovative high performance materials, accelerated construction techniques, precast concrete elements, and new design methodology.

CASE STUDY 1: **EVALUATION AND TESTING OF ULTRA HIGH PERFORMANCE CONCRETE BULB TEE GIRDERS** [Wipf et al., 2008; Degen, 2006; Moore and Bierwagen, 2006 a; Moore and Bierwagen, 2006 b]

INTRODUCTION

The first UHPC highway bridge in the United States was constructed as a cooperative effort among the Iowa DOT, Wapello County, Federal Highway Administration (FHWA), and ISU in the fall of 2005. The UHPC bridge is located in Wapello County, Iowa. The Iowa DOT was interested in investigating the use of new high performance materials to improve bridge durability. The project was made possible through funding from the FHWA and the Iowa Highway Research Board (IHRB).

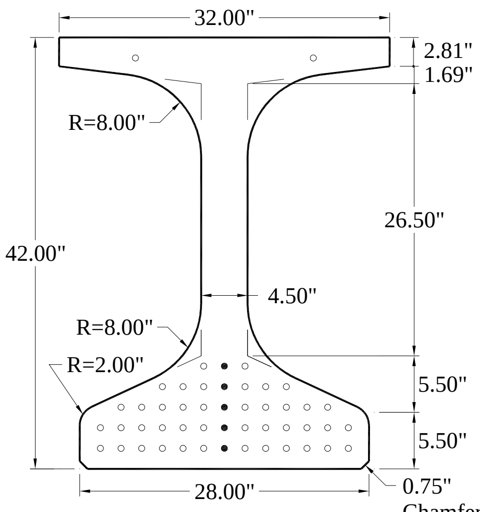
OBJECTIVE AND SCOPE

The broad research objective and scope of this project included design, documentation, and construction of the UHPC bridge. Limited research in the area of UHPC and the lack of existing design guidelines for bridge applications necessitated an extensive study. Thus laboratory and field research was conducted to determine the structural performance of the bridge and bridge components to ensure the viability of the UHPC bridge design.

Background information, design and construction information, large-scale laboratory flexure testing and field testing of the constructed bridge are presented in this paper.

BRIDGE DESCRIPTION

The bridge cross section consists of three slightly modified standard Iowa DOT Bulb Tee C girders that are 111 ft long with steel fibers in lieu of shear reinforcement (see Fig. 5a) . The compressive strength of UHPC generally ranges from 16,000 psi up to 30,000 psi and the tensile strength, usually neglected in concrete, can be as high as 1,700 psi. The UHPC used in this project is a specific brand manufactured by Lafarge North America and is known as Ductal®. The final design compressive strength used was 24,000 psi with an allowable tension stress at service of 600 psi. The nearly completed bridge is shown in Fig. 5b.



a. Midspan cross section

b. Bridge under construction

Figure. 5 Wapello County UHPC bridge beams

DESCRIPTION OF INSTRUMENTATION AND MONITORING

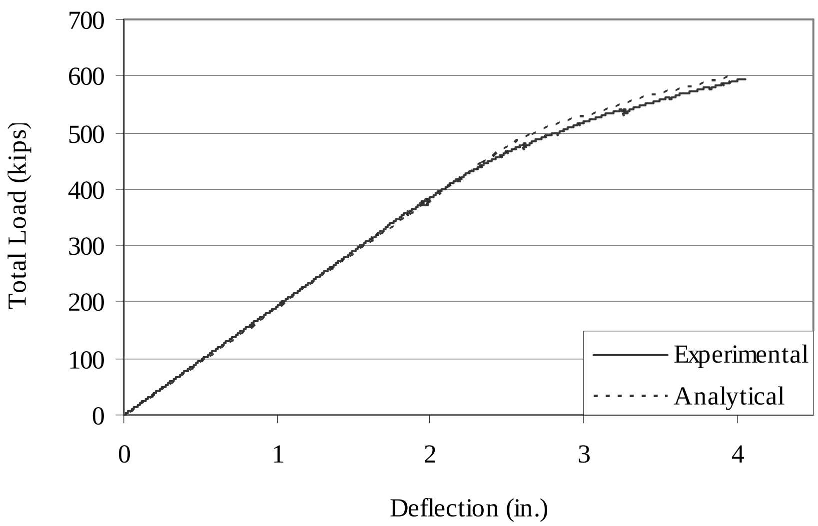
Large scale and small scale laboratory testing was completed by ISU to collect information about the structural performance of UHPC and to validate the bridge design procedure. Flexure and shear tests (service and strength level) were performed on a full scale laboratory beam with a cross section equivalent to the actual bridge beams but with a reduced span of 71 ft. Additional shear tests were performed on small scale model specimens. Strain, deflection, and load data were obtained during the testing to characterize design parameters for the bridge beams, including required prestressing, strand slip, and prestress losses.

Field testing of the completed bridge was also performed to assess the structural performance of the UHPC bridge and to validate the design assumptions. Two tests were conducted using essentially the same test configuration. Girder strain data were collected at midspan and quarter span and near the abutment. Deck strain data were also utilized. Loads were applied by a loaded tandem axle truck.

VALUE OF TESTING AND EVALUATION

The laboratory testing provided important design parameter information for the UHPC bridge since no formal design criteria existed at the time (see Fig. 6). The subsequent testing of the completed bridge provided validation of the selected design parameters. A baseline set of field data now exist for use in further evaluation of the UHPC bridge performance over time. The Iowa DOT has gained confidence in implementing future UHPC projects.

a. Shear test configuration



b. Ultimate shear test results compared to analytical predictions

Figure 6. Full scale testing was used to confirm both the service and ultimate strength levels for bending, shear, and shear plus bending.

CASE STUDY 2: EVALUATION AND TESTING OF AN ULTRA HIGH PERFORMANCE CONCRETE BRIDGE USING PI GIRDERS [Keierleber, et al., 2007]

INTRODUCTION

As discussed in Case Study 1, the first UHPC highway bridge in the United States (using bulb tee girders) was constructed in Wapello County, Iowa during the fall of 2005. The shape is not the most efficient use of the material properties of UHPC, so a new girder shape was conceived based on conventional engineering principles. Initial research of the first generation Pi girder (see Fig. 7) was conducted by the FHWA at the Turner-Fairbank Laboratory. Based on their test results, it was recommended that changes be made to that girder shape before implementation on a demonstration bridge.

Figure 7. First generation Pi girder

Currently, the Iowa DOT is working on the next generation UHPC girder shape (Pi shape) bridge in Buchanan County, Iowa. The demonstration project is being performed in collaboration with Buchanan County, Iowa, the FHWA, and ISU. This bridge will once again put Iowa at the national forefront of bridge design and construction implementation for use of the UHPC shape. This is another project conducted by the Iowa DOT to investigate means of designing and constructing more durable bridges.

OBJECTIVE AND SCOPE

The overall research objective and scope of this project include the design, documentation, construction and evaluation of the UHPC bridge using a second generation Pi girder. Since no formal design criteria exist for this bridge material or this girder shape, finite element modeling was performed to determine the adequacy of preliminary design parameters. As this project is currently underway, subsequent laboratory testing, field load testing, and field research will be conducted to determine the structural performance of the bridge and bridge components to ensure the viability of the UHPC bridge design.

BRIDGE DESCRIPTION

The demonstration bridge will have a total length of 110 ft and will consist of three spans. Only the center span will utilize the UHPC Pi girder (see Fig. 8). The other two spans will consist of conventionally reinforced concrete slab. The Pi girders will have a center to center span of 50 ft. The bridge cross section consists of three Pi girders, each 8 ft-4 in wide, giving a total bridge width of 25 ft. The Pi girders are prestressed in the bulbs (girder web) using eighteen 0.6 in diameter strands. The overall girder depth is 2 ft-9 in and the girder webs are 3 ¾ in wide. The girder deck is 4 1/8 in deep. The design compressive strength of the Pi girders is 21.5 ksi. The girder webs will be stiffened with structural tube diaphragms between the bulbs. Shear keys will be used to provide lateral transfer of loads across the adjacent girder decks.

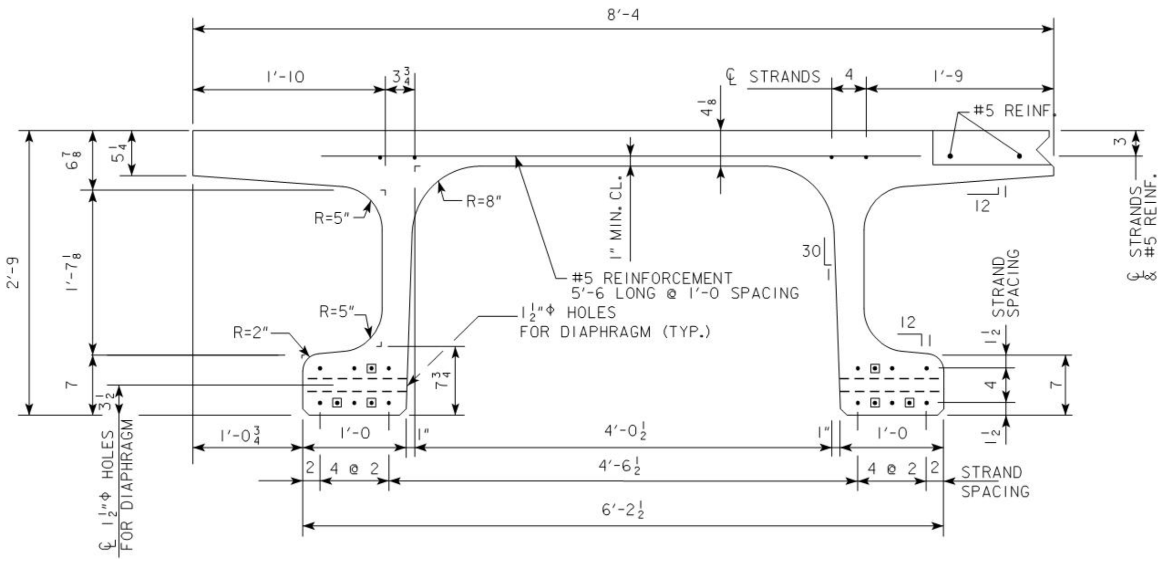


Figure 8. Typical cross section of the Pi girder as designed for the Buchanan County Bridge.

DESCRIPTION OF INSTRUMENTATION AND MONITORING

As noted above, the bridge has not yet been constructed. Girder casting is expected to begin in July of 2008. Once constructed, field load tests will be conducted to determine the structural performance and to validate the design assumptions. Two tests over a period of one year will be conducted, the first one immediately after the bridge construction. Critical strain and deflection data will be measured to assess the following:

- Maximum girder deflection
- Lateral load distribution
- Maximum service level flexural strain/stress
- Effectiveness of the shear key design
- Girder deck strain/stress levels

Prior to the field testing, complementary testing and evaluation of two 25 ft long Pi girders will be performed in cooperation with the FHWA at the FHWA Turner-Fairbank Laboratory. The laboratory testing will allow flexural and shear strength limit state characteristics to be determined.

VALUE OF TESTING AND EVALUATION

Finite element modeling results provided important design parameter information for the design of the UHPC bridge, since no formal design criteria existed. The subsequent testing of the constructed bridge will provide validation of the selected design parameters. A baseline set of field data will be used in further evaluation of the UHPC bridge performance over time. As indicated in Case Study 1, the Iowa DOT will continue to gain confidence in future implementation of UHPC as the result of this research.

CASE STUDY 3: LABORATORY, FIELD TESTING, AND EVALUATION OF PRECAST BRIDGE ELEMENTS FOR ACCELERATED CONSTRUCTION PRACTICES – BOONE COUNTY [Bowers, et al., 2007; Abu-Hawash, 2007 b]

INTRODUCTION

Constructing and rehabilitating bridges with minimal impact on traffic has become a transportation priority as traffic volumes increase nationwide. Furthermore, the demand to increase the safety of travelling public and construction workers in construction zones has made it imperative to “Get in, Get out, and Stay out” [NCHRP, 2003]. With that in mind, rapid construction has several advantages over traditional construction methods. The six main advantages of rapid construction technology are:

- Minimize traffic disruption
- Improve work zone safety
- Minimize environmental impact
- Improve constructability
- Increase quality
- Lower life-cycle cost

As the Iowa DOT was working toward the implementation of rapid construction methods to improve bridge durability and to minimize construction time, a demonstration project in Boone County was identified. The rapid construction bridge project was the result of collaboration among the Iowa DOT, FHWA, Boone County, and ISU. The project was funded by the FHWA and the IHRB.

OBJECTIVE AND SCOPE

The objective of this project was to document the design and construction of the Boone County Bridge and to evaluate the structural performance of both superstructure and substructure components, as well as the completed bridge. The project scope included both laboratory testing of full-scale components and field testing of the bridge during construction and after construction.

BRIDGE DESCRIPTION

The structure is a continuous 151 ft x 33 ft, three-span bridge with a four-girder cross section. The prestressed concrete girders support a full-depth, precast concrete deck (Fig. 9a). The 8-in thick deck panels span half the width of the bridge (8 ft and 1 in length) and were prestressed in the transverse direction. Each panel had two full-depth channels, located over the prestressed girders, for longitudinal post-tensioning (Fig. 9b). Once the panels were erected, the entire bridge deck was post-tensioned in the longitudinal direction, after which concrete was cast in the four post-tensioning channels. Although this exact design had not been previously constructed, a similar partial-depth deck system has been constructed and tested in Nebraska [Badie, et al., 1998].

a. Completed bridge

b. Deck panels in place before grouting

Figure 9. Boone County bridge during and after construction

Precast abutment caps and precast pier caps supported on H-piling and pipe piling, respectively, comprised the substructure (Fig. 10). The units were reinforced with mild reinforcing and included blockouts for the piling that were created using corrugated metal pipe (CMP). The fairly conservative connection design was later validated by testing. A high early strength concrete mix was used for filling the substructure blockouts.

DESCRIPTION OF INSTRUMENTATION AND MONITORING

Large scale laboratory testing was completed by ISU to collect information about the structural performance of both the substructure and superstructure elements and to validate the bridge design procedure. Flexure and shear tests (service and strength level) were performed. Strain, deflection and load data were obtained during the testing to characterize design parameters. Additionally, tests were performed to determine the flowability of the grout material in the deck joints.

a. Setting precast abutment

b. Abutment CMP blockout

Figure 10. Substructure elements

Field testing of the completed bridge was also performed to assess the structural performance of the bridge and to validate the design assumptions. One field test has been conducted, and the final test is scheduled for June 2008. Girder strain data and deflection data were collected at midspan, quarter span, and near the abutment. Deck strain data were also utilized. Loads were applied by loaded tandem axle trucks.

VALUE OF TESTING AND EVALUATION

The laboratory testing provided important design service and strength level parameter information for the Boone County superstructure and substructure elements of the bridge (see Fig. 11 thru 14). The subsequent testing of the constructed bridge provided validation of the selected design parameters. A baseline set of field data now exist for use in further evaluation of the bridge performance over time. The Iowa DOT has used the experience and results from this study to implement similar, modified rapid construction concepts on other bridges.

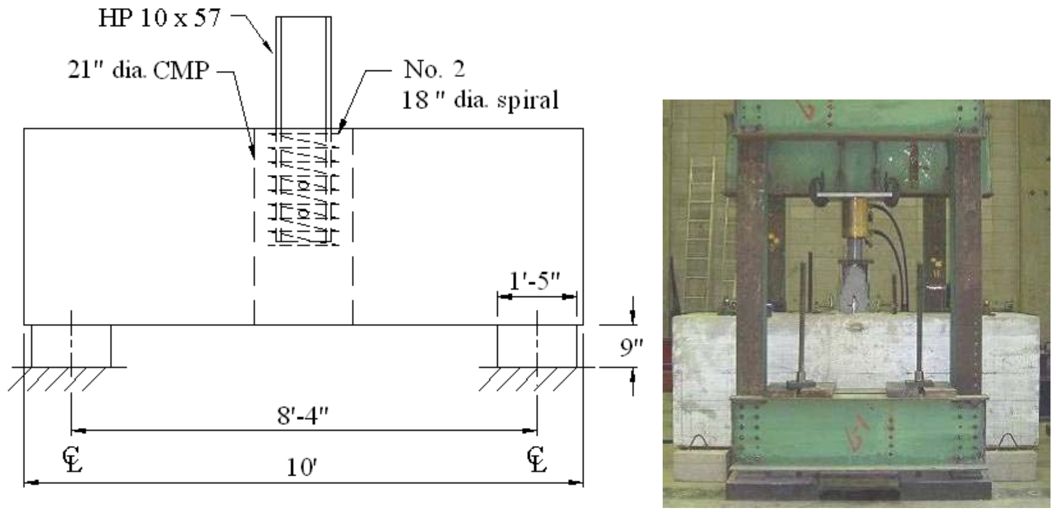


Figure 11. Simulated and full scale mock up of abutment pile/cap beam connection to measure structural capacity and potential slip.

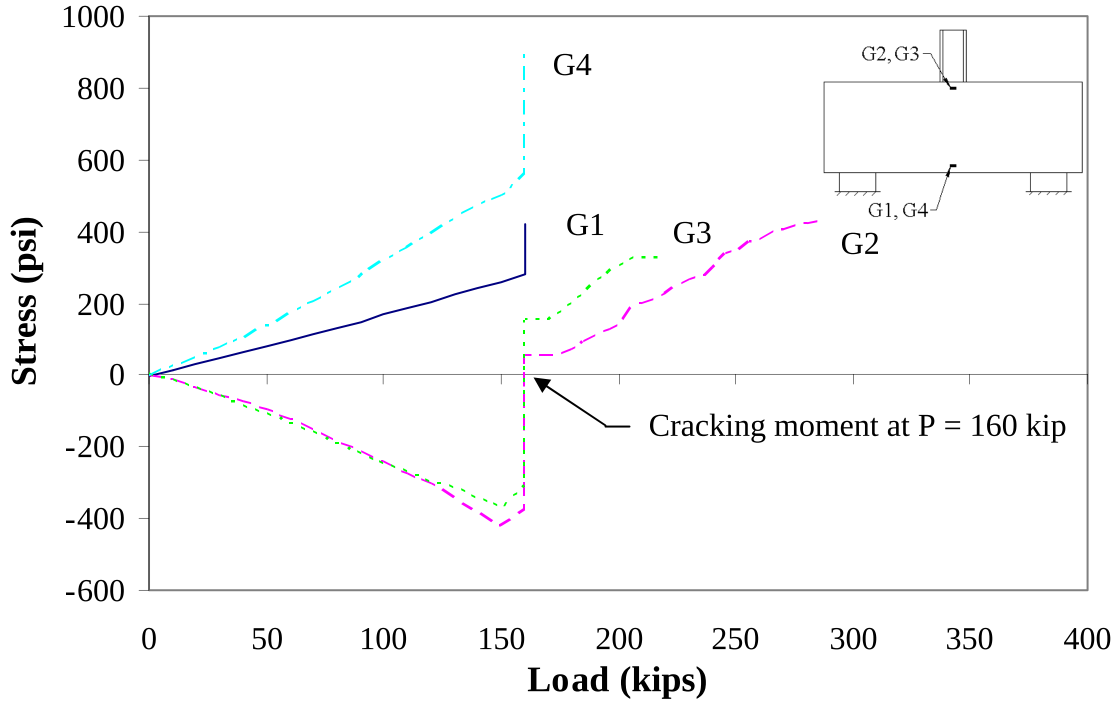


Figure 12. Concrete stresses in one of the substructure specimens

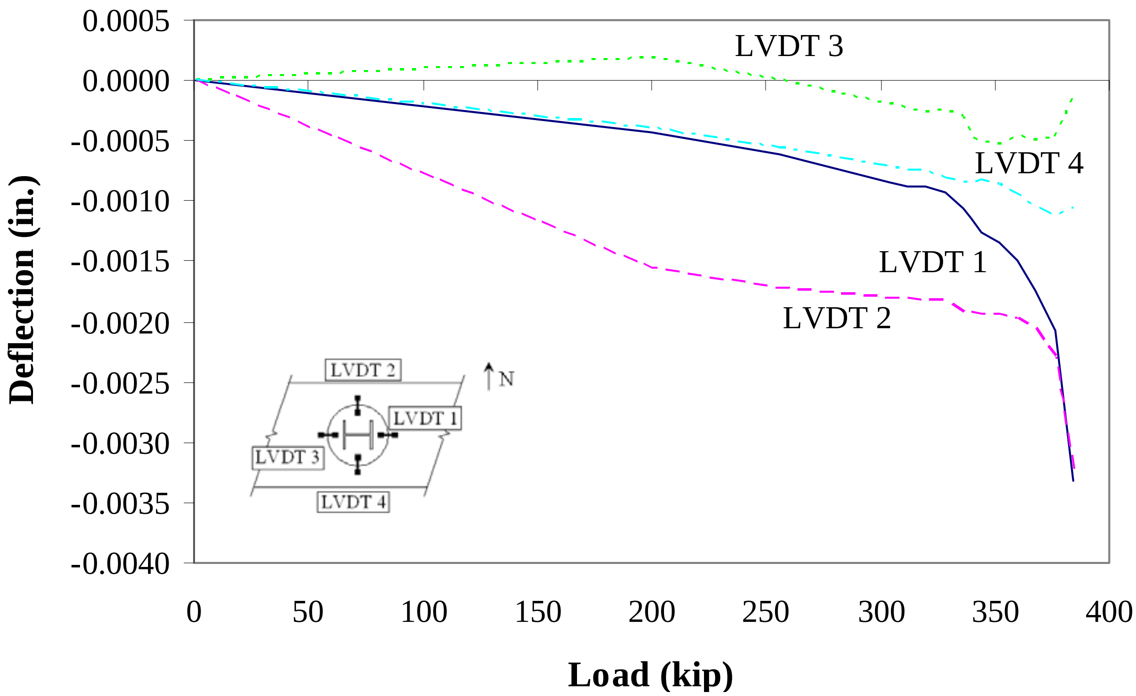


Figure 13. Differential deflection (slip) of pile relative to grouted connection for substructure specimen.

Figure 14. PT strand vibrating wire gage to measure strand force during tensioning operation and to subsequently measure deck strain after bridge construction.

CASE STUDY 4: LABORATORY, FIELD TESTING, AND EVALUATION OF PRECAST BRIDGE ELEMENTS FOR ACCELERATED CONSTRUCTION PRACTICES – MADISON COUNTY [Abu-Hawash, 2007 b]

INTRODUCTION

Recently, there has been increased interest in constructing bridges that last longer, are less expensive, and take less time to construct. The idea is to generally increase the cost-effectiveness of bridges by increasing their durability (i.e., useful life) and minimizing disruptions to the traveling public. There may be many ways to achieve more durable, less expensive and rapidly constructed structures, however, the most commonly discussed ideas currently include using some form of precast, segmental construction.

OBJECTIVE AND SCOPE

The objective of this project was to perform laboratory and field tests to evaluate the Madison County precast bridge components and assess the overall design, construction, and bridge performance. The project scope included design of the substructure and superstructure, fabrication and construction observations, laboratory testing of box girder specimens, live load field testing, and corrosion monitoring.

BRIDGE DESCRIPTION

The Madison County precast bridge is a longitudinally pretensioned, two-lane, single span, box girder bridge spanning 46 ft-8 in center to center of supports and has an out-to-out deck width of 24 ft-1 in (see Fig. 15). The bridge consisted of six 2 ft x 4 ft box girders placed side by side with a hand tightened transverse tie located at the midspan. The supporting substructure consists of five HP10x42 piles at each abutment and a precast cap beam. The precast cap beam is 27 ft-4 in long, 3 ft wide, and varies in depth from 3 ft-6 in at the ends to 3 ft-9 in in the middle. The cap beams had five corrugated metal pipe blockouts placed vertically at the pile locations for connection to the piles.

a. Precast abutment b. Completed bridge

Figure 15. Precast elements of Madison County bridge

DESCRIPTION OF INSTRUMENTATION AND MONITORING

Two box girders were tested in the laboratory to determine the following behaviors:

- Transverse post-tensioning stress
- Girder-to-girder differential displacement

- Girder longitudinal strain
- Girder deflection
- Girder principal strains (strain rosettes)

The field test consisted of static and dynamic live load testing with the following behaviors monitored:

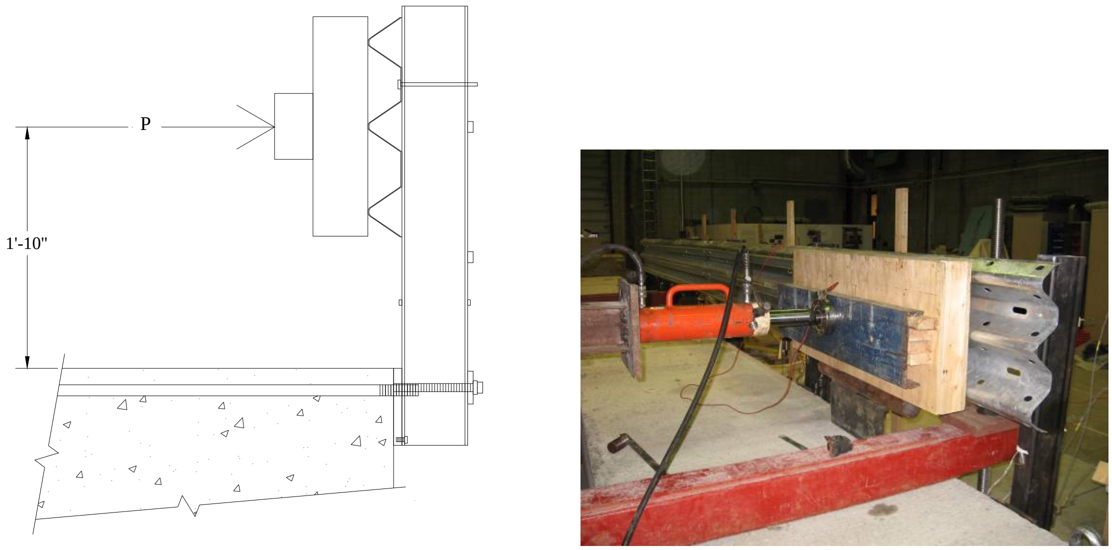
- Bridge longitudinal strains at midspan, quarterspan, and eighthspan
- Girder-to-girder differential displacement at midspan and quarterspan
- Bridge acceleration
- Strand corrosion

VALUE OF TESTING AND EVALUATION

The laboratory tests (see Fig. 16 and 17) indicated that the shear key between adjacent girders is adequate for transferring load (load distribution) with only hand tight post-tensioning force, and the service limit state stresses were not exceeded by service level loads. Similarly, from field testing (Fig. 18), the differential girder deflection was minimal, and the load distribution factor of 0.5 that was used for the design of the simply supported beams was adequate and is recommended for future designs.

a. Girders with the shear key cast. b. Post-tensioning bar and jack

Figure 16. Photographs of laboratory setup for variable post-tensioning force tests to determine panel load sharing as a function of post-tensioning



a. profile view of test setup b. photograph of laboratory setup

Figure 17. Guardrail connection test setup to determine strength limit state of the guardrail system

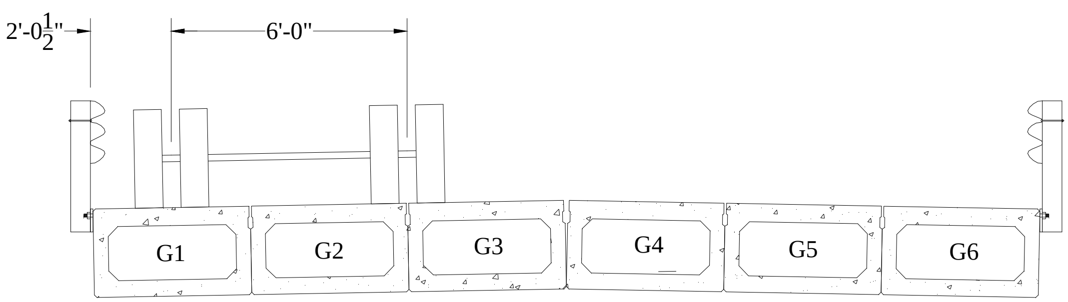


Figure 18. One of several transverse load positions of load truck to evaluate the service level bridge performance.

CASE STUDY 5: MONITORING AND EVALUATION OF ACCELERATED CONSTRUCTION CONCEPTS ON THE 24TH STREET BRIDGE [Abu-Hawash, et al., 2007 a]

INTRODUCTION

During the last several years, the Iowa DOT has begun planning and design efforts on the implementation of accelerated bridge construction (ABC). Prior to the 24th St Bridge project, the Iowa DOT had designed and implemented ABC on a bridge project using a prestressed precast deck system with post-tensioning on prestressed girder bridges. The 24th St project provided an opportunity to modify the previously used deck system and to implement it on another project allowing further evolution of ABC concepts.

OBJECTIVE AND SCOPE

The objective of this project is to perform laboratory testing to address specific ABC design and construction questions. Field tests will be used to evaluate the performance of various bridge components and assess the overall design, and construction. The scope also includes fabrication and construction observations and monitoring, and long-term corrosion monitoring.

BRIDGE DESCRIPTION

The 24th Street bridge is a two-span 353 ft continuous steel girder bridge with composite precast deck panels over Interstate 29/80 in Council Bluffs, Iowa (Fig. 19). The bridge has an overall width of 104 ft – 8 in including sidewalks and shared use lane. The bridge deck has two rows of 54 ft – 4 in by 10 ft by 8 in thick transverse precast concrete deck panels. The deck panels are prestressed transversely and post-tensioned longitudinally after erection. The deck panels were compositely bonded to the girders by shear studs and grouted stud pockets.

a. Precast deck reinforcing

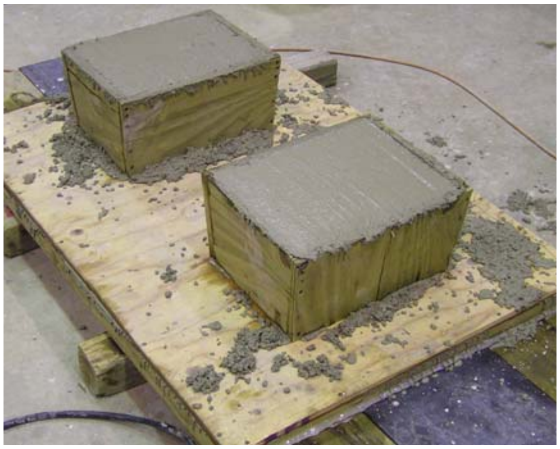
b. Girder placement

Figure 19. Construction of 24th Street bridge

DESCRIPTION OF INSTRUMENTATION AND MONITORING

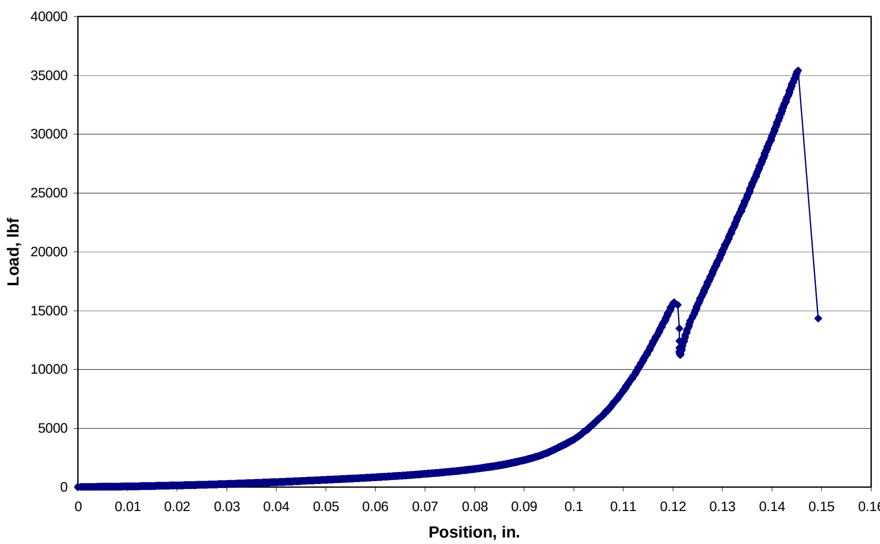
The laboratory testing program (see Fig. 20) included the following:

- Shear stud bending test
- Grout consolidation and flow at stud pockets
- Transverse joint surface treatment and joint shear
- Duct splice performance



a. Shear stud pocket mock-up

b. Panel-to-panel interface shear strength testing



c. Typical shear strength results

Figure 20. Laboratory mock-ups were used to verify both constructability aspects as well as design assumptions

The field test will include monitoring of bridge elements during construction and live load testing after bridge completion. The following behaviors will be monitored:

- Deck panel strains during construction
- Joint stress during strand post-tensioning
- Bridge strain
- Bridge deflection
- Differential joint movement
- Bridge acceleration characteristics

- Strand corrosion

VALUE OF TESTING AND EVALUATION

Based upon previous ABC projects, and from the laboratory test conducted by the Bridge Engineering Center, the Iowa DOT was able to implement design concepts and ideas confidently for the construction of the 24th Street Bridge. Currently the bridge is under construction. Instrumentation is being installed, but no field data have been obtained.

CASE STUDY 6: INSTRUMENTATION AND MONITORING OF INTEGRAL BRIDGE ABUTMENT-TO-APPROACH SLAB CONNECTION [Bierwagen, et al., 2007]

INTRODUCTION

The Iowa DOT has recognized that approach slab pavements of integral abutment bridges are prone to settlement and cracking, which manifests itself as the “bump at the end of the bridge”. The bump is not a significant safety problem; rather it is an expensive maintenance issue. A commonly recommended solution is to integrally attach the approach slab to the bridge abutment, which moves the expansion joint typically found at the approach slab/abutment interface to a location further from the bridge where soil settlement is less of a concern and maintenance is easier.

OBJECTIVE AND SCOPE

The primary objective of this investigation was to evaluate the approach slab performance and the impacts the approach slabs have on the bridge. To encompass all aspects of the system and to obtain meaningful conclusions, several behaviors were studied and monitored. Included in the monitoring were abutment movement, bridge girder strain changes, approach slab strain changes, approach slab joint displacements, post-tensioning strain, and abutment pile strain changes. The project scope also involved a literature review, survey of midwest departments of transportation current practices, and periodic visual inspection of the subject bridges.

BRIDGE DESCRIPTION

Two new side-by-side integral abutment bridges on new Iowa 60 in O’Brien County, Iowa were chosen as test bridges for two different types of approach slabs attached to the bridge abutments. The bridges are twin three-span-continuous prestressed concrete girder bridges, 303 ft x 40 ft, with a right-hand-ahead 30 degree skew angle. The end spans are 90 ft - 9 in and the interior span measures 121 ft - 6 in While the bridges themselves are identical, the approach slabs differ from the northbound bridge to the southbound bridge. In both cases, however, the approach slabs are tied to the bridges. In the northbound direction, precast prestressed panels are used, while in the southbound direction a standard cast-in-place approach slab is used (see Fig. 21).

a. Northbound approach slab

b. Southbound approach slab

Figure 21. Precast and cast-in-place approach slabs

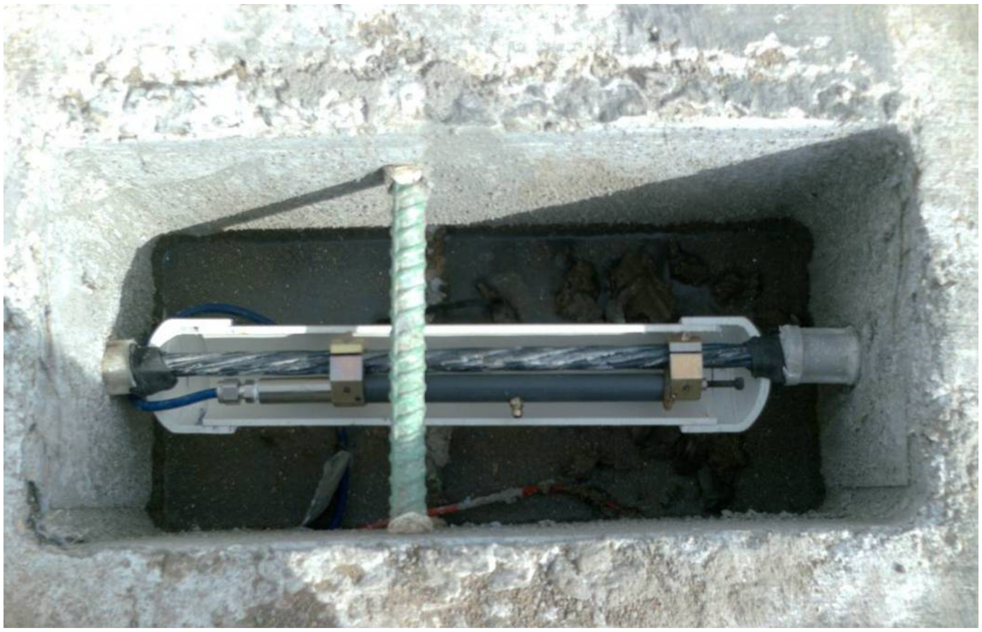
DESCRIPTION OF INSTRUMENTATION AND MONITORING

A wide variety of sensors were installed on the bridge and the approach pavement and monitored for a 12 month testing period (Fig. 22a). The following behaviors were monitored:

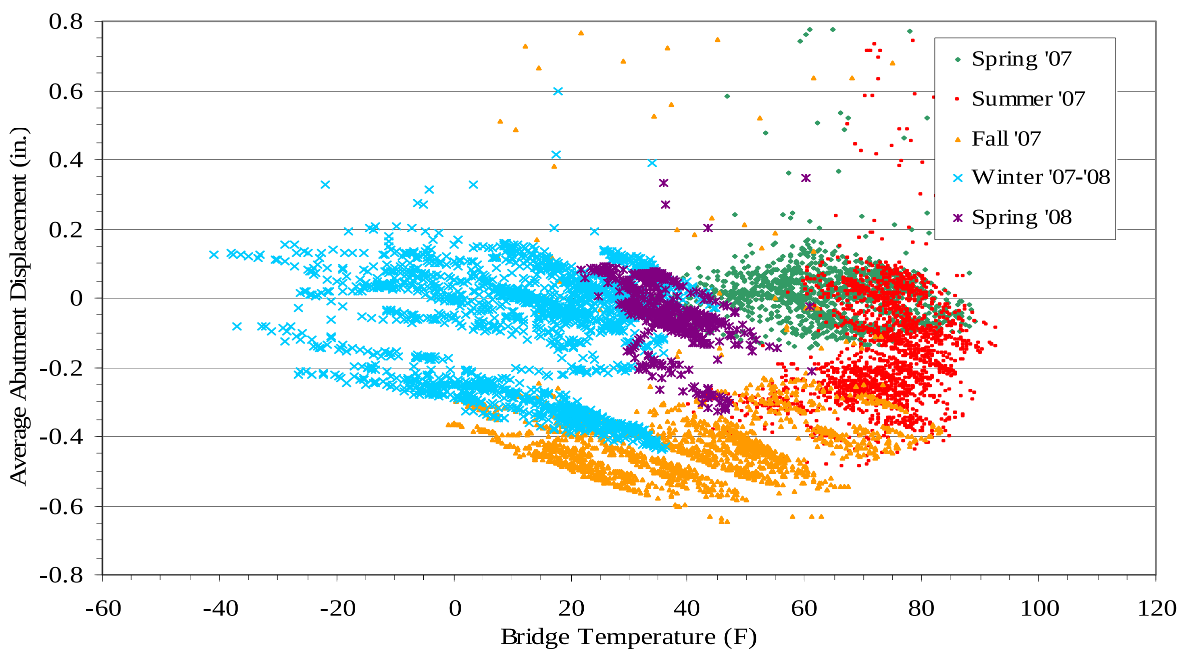
- Temperature
- Bridge abutment movement (translation and rotation)
- Bridge girder strain changes
- Approach slab strain changes
- Post-tensioning strand losses
- Approach slab joint relative displacement
- Bridge abutment pile strain changes

VALUE OF TESTING AND EVALUATION

From this testing the Bridge Engineering Center was able to determine that the approach slabs do affect the bridge performance, that there exists a force at the expansion joint, and that the general response of the slab (see Fig. 22b) is controlled by friction ratcheting. Although many questions were answered, several more questions arose during the testing that still needs to be answered. Overall, it appears that for both systems (precast and cast-in-place), the tying of the approach slab to the abutment is working and is recommended for use on other bridges to gain greater experience with this technique.



a. Typical example of embedded instrumentation



b. Typical performance measurements

Figure 22. Both bridge and approach slab were monitored to investigate the performance and interaction of the two.

CASE STUDY 7: TESTING AND EVALUATION OF PRECAST PAVING NOTCH SYSTEM [LaViolette et al., 2007]

INTRODUCTION

Bridge approach pavement settlement and the resulting formation of bumps at the end of bridges is a recurring problem on a number of Iowa bridges. One of the contributing factors in this settlement is failure of the bridge paving notch. A paving notch (also known as a corbel or a paving support) consists of a horizontal shelf constructed on the rear of a bridge abutment and is used to support the adjacent roadway pavement. Over time, these paving notches have been observed to deteriorate/fail due to a number of conditions including horizontal abutment movement due to seasonal temperature changes, loss of backfill materials by erosion and so on. In some cases, the condition of the paving notch deterioration may not be noticed until the deterioration reaches a critical state and the approach pavement is removed.

Bridge owners are frequently faced by the need to replace critical bridge components during strictly limited or overnight road closure periods. The conventional replacement method, however, requires that the bridge be taken out of service for an extended period of time, which disrupts the traveling public. The notable number of bridges that exhibit the failing paving notch problem and, more importantly, their location on highly traveled roadways necessitate the development of a standardized, much more quickly-installed replacement method. With a standardized system, situations where the deterioration is unknown until approach pavement removal could be addressed with minimal traffic disruptions.

OBJECTIVE AND SCOPE

The objective of this research project was (1) to develop new paving notch system that can be installed with a single overnight bridge closure, and (2) to verify and investigate the structural capacity and the feasibility of the system. Researchers at ISU performed full-scale laboratory testing of the paving notch replacement system. Following the successful laboratory testing, a field implementation site in Marion County, Iowa was selected. The field-implemented system was modified from the original design based on the findings and lessons learned from the laboratory testing.

BRIDGE SYSTEM DESCRIPTION

The precast paving notch system was intended for use in either new construction or as rapid replacement that can be installed in single-lane-widths to allow for staged construction under traffic with a single overnight bridge closure. The system consists of a rectangular, precast concrete element that is connected to the rear of the abutment using high-strength threaded steel rods and an epoxy adhesive that is similar to that used in segmental bridge construction.

DESCRIPTION OF INSTRUMENTATION AND MONITORING

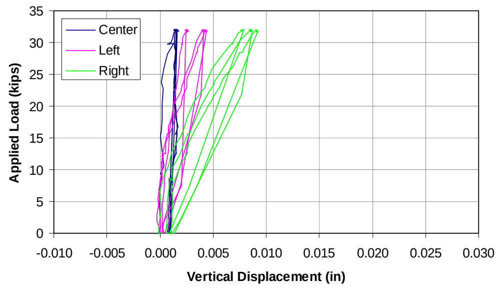
The laboratory testing program consisted of a series of static and dynamic load tests conducted in several phases to investigate the system abilities to sustain repeated cyclic and ultimate loads (Fig. 23). The test procedure for loading the specimens included application

Figure 23. Laboratory test set-up of precast paving notch system

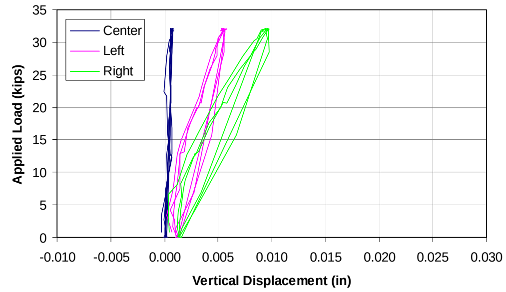
of a single point load or a combination of two point loads applied directly to the paving notch specimens. The collected data focused on measurement of applied force to the notch block and slip displacement of the block relative to a fixed base. From the testing the following was concluded:

- When epoxy adhesives are used, the connection of the precast paving notch to the abutment can be adequately achieved by hand-tightening ¾ in diameter stainless steel threaded rods that are drilled and grouted approximately 10 in into the abutment.
- The use of additional set (a second row) of stainless threaded rods improved the ultimate load carrying capacity of the precast paving notch system.
- In comparison to the ultimate strength of the Iowa DOT's current CIP paving notch repair system, the proposed precast paving notch system showed larger ultimate load carrying capacity.
- No significant slippage was observed during cyclic testing.
- The use of different materials and reinforcing steel for the precast paving notch specimen had little influence on the overall performance of the system; none of the tested precast paving notch specimens failed during the testing. In all cases, failures occurred at the connection of the system (epoxy adhesives and adjacent abutment concrete).

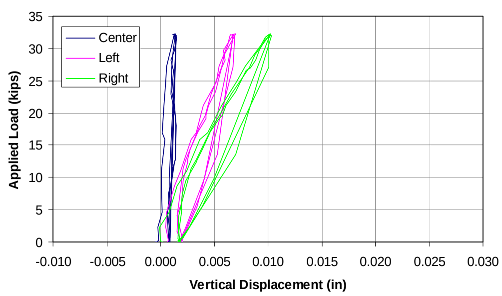
Based on the findings and lessons learned from the laboratory testing (see Fig. 24), the design was modified for field implementation at a site in Marion County, Iowa. The new system is shown in Fig. 25. Deflection slip of the notch at four locations across the notch is being measured (along with strain on the block at those locations). A cell phone alarm has been established based on a deflection slip threshold in the event of an excessive movement.



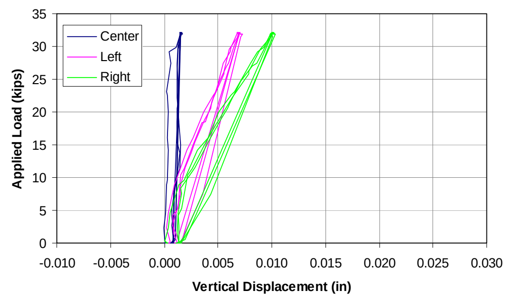
a. PT force: 77 kips



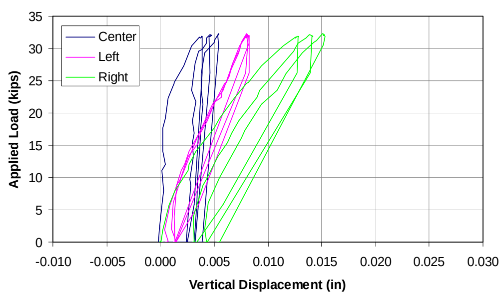
b. PT force: 64 kips



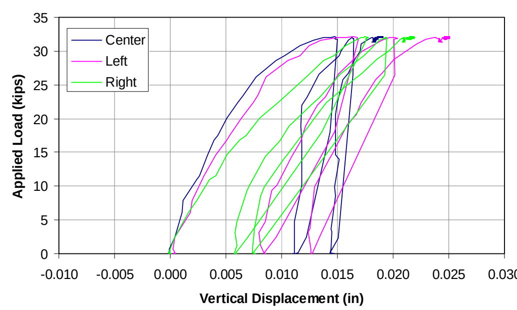
c. PT force: 51 kips



d. PT force: 38 kips



e. PT force: 26 kips



f. PT force: 13 kips

Figure 24. Laboratory results showing the influence of post-tension force on performance

Figure 25. Field implementation of precast paving notch system on bridge

VALUE OF TESTING AND EVALUATION

The testing and evaluation illustrated that a precast paving notch replacement system exhibits a very strong potential for replacing failed approach slab supports much more quickly than is possible with current cast-in-place concrete methods. The combination of this research and the other work that was discussed in the previous section will provide an accelerated method for replacing the entire bridge approach pavement system during a limited (overnight) bridge closure.

CASE STUDY 8: **CONSTRUCTION TESTING AND EVALUATION OF ARCH PEDESTRIAN BRIDGE USING PRECAST DECK UNITS [**LaViolette, et. al., 2007]

INTRODUCTION

The Iowa DOT recently rebuilt the entire downtown I-235 freeway to current design standards, which will improve capacity and greatly reduce the number of traffic accidents. As part of this reconstruction, the Iowa DOT and the City of Des Moines wanted to create a set of signature bridges that would provide a “gateway” into the city. Three basket-handle arch pedestrian bridges (see Fig. 26a) were designed to provide a dramatic visual entryway into the city. Some cracking occurred in the precast concrete panels near the hanger connections, mostly in the first bridge. Monitoring of arch hangers was performed on the last two arch bridges to make sure that a consistent and adequate level of hanger forces were maintained during construction.

OBJECTIVE AND SCOPE

The ISU Bridge Engineering Center evaluated the structural performance of the hanger rods and monitored load distribution on the second and third pedestrian bridges which were constructed near 40th and 44th Streets in Des Moines during the summer of 2005.

BRIDGE DESCRIPTION

The arch ribs consist of tubular steel sections which are tapered in both the horizontal and vertical directions from 19.6 in x 27.6 in at the crown to 29.5 in x 49.2 in at the base. The arch ribs are inclined at approximately 10 degrees and are connected at the crown by a bolted diaphragm. The bridges utilize a precast, post-tensioned concrete deck system and represent the first application of post tensioned precast, segmental construction on the Iowa highway system. The panels were segmentally erected and longitudinally post-tensioned using high-strength threaded steel rods meeting the requirements of ASTM A722 (see Fig. 26b). In the segmental erection process, the mating faces of adjacent panels were coated with a specialized epoxy adhesive (Unitex Segmental Adhesive) and the panels were then stressed together using a hollow-core jack. The panels are supported by 1.42 in diameter, high-strength steel bar hangers. The hangers are connected to the arch rib at anchor points located at 13.78 ft spaces.

DESCRIPTION OF INSTRUMENTATION AND MONITORING

A vibration technique was used to measure the axial force in the arch hangers during construction. Accelerometers were mounted to the hangers approximately 5 ft above the deck panels using steel clamps and were oriented with their primary axis perpendicular to the centerline of the bridge. An acceleration record was collected for each hanger by manually exciting the hanger using a suddenly applied, horizontal force approximately 4 ft above deck level. The external force was applied perpendicular to the bridge centerline. Data were collected for a period of approximately 10 sec. from which free vibration records were utilized for data processing. The test was repeated at least two times per hanger to verify the reproducibility of the data. Commercial software was used for processing the free vibration data and to obtain the natural frequencies. Hanger tensile forces were computed based on string and beam vibration theory.

a. Completed bridge b. Precast deck slab units

Figure 26. One of the three pedestrian arch bridges and precise deck component on I-235 in Des Moines, Iowa

VALUE OF TESTING AND EVALUATION

The testing was critical in allowing the bridge contractor to maintain hanger force levels within tolerable limits (see Fig. 27). As a result, the deck cracking noted in the first pedestrian bridge was not a significant problem in the subsequent two arch bridges. The use of the vibration method has been validated as a time effective and cost effective method that has been used on multiple occasions since the pedestrian bridges were constructed, most recently this spring.

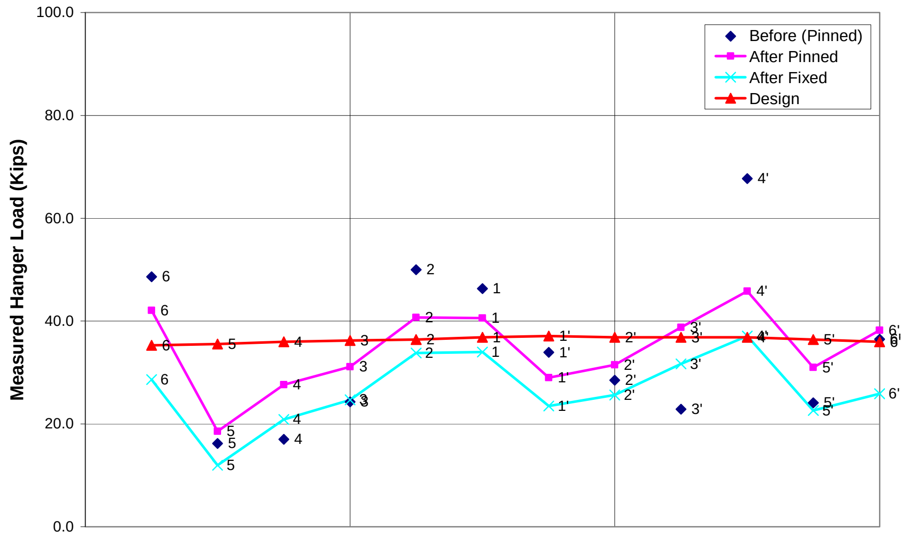


Figure 27. Hanger forces for east arch of the 44th Street Bridge after adjustment

CONCLUSIONS

The inclusion of testing and monitoring by the Iowa DOT has played a major role in the success of the projects where design innovations and new high performance materials have been utilized. Laboratory testing of new design details and materials has given bridge engineers confidence in proposed design solutions. Furthermore, the testing provided opportunities to make timely modifications, if needed, during the design phase, thus reducing the risk of failures. Additionally, field testing and long term monitoring of various constructed components as well as entire bridges, has provided the Iowa DOT with a stronger level of confidence and better understanding of potential structural performance.

In the process of performing the testing and monitoring associated with these innovative projects, researchers at the ISU Bridge Engineering Center have been able to implement state of the art instrumentation and make contributions to the state of practice in the field of bridge testing and structural health monitoring.

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